Characterization of particle and gas phase pollutant emissions from heavy- and light-duty vehicles in a California roadway tunnel

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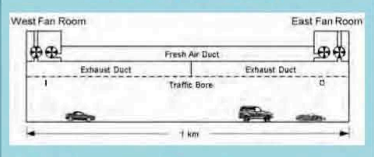
Motivation

- Roadway tunnels facilitate characterization of large numbers of in-use vehicles
- Multi-year pollutant measurements reflect changes due to emission controls, recent changes in fuel composition and vehicle turnover
- Emission factors measured in this study extend our record of light-duty, gas-phase pollutants to ten years
- Particle-phase pollutant measurements are desired to establish trends for light- and heavy-duty vehicles – last measured in 1997

Caldecott Tunnel 2004



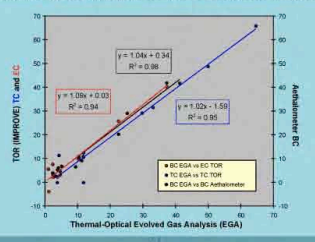
- Heavily used tunnel east of San Francisco Bay
- Pollutants measured at inlet (I) and outlet (O) of tunnel
- Exhaust fans turned off during emission factor measurements
- Two tunnel bores: 1) light-duty (gasoline) vehicles and 2) mixed light-duty and heavy-duty (diesel) vehicles
- In mixed vehicle bore, pollutant apportionment based on measured LD emission ratios is used to estimate HD emission factors

Measurements

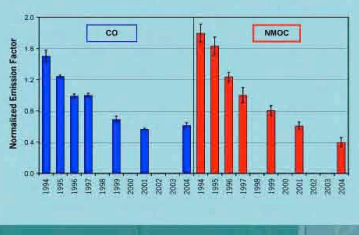
- Pollutants:
  - CO, CO_2, Non-methane organic compounds (NMOC)
  - Particle mass ($PM_{2.5}$)
  - Total, black and organic carbon (TC,BC,OC)
  - Polycyclic aromatic hydrocarbons (PAH)
  - Particle size distribution (SMPS)
- Optical properties:
  - Light-extinction coefficient (cavity ring-down)
  - Spectral absorption (spectrometer and 7λ aethalometer)
- Traffic characterization: volume (#/hr) and type (based on # axles)
- Emission factors: pollutant mass emitted per volume of fuel burned

$$E_P = \left(\frac{\Delta[P]}{\Delta[CO_2]+\Delta[CO]} \right) w_C \rho_f$$

Comparison of Carbon Concentrations (μg m^{-3}) Thermal-Optical Analysis Methods and an Aethalometer



Trends in Light-Duty Gas-Phase Pollutant Emission Factors (normalized to 1997 g/L value)



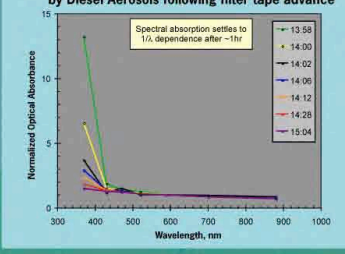
2004 Particle-phase Emission Factors

Grams per litre

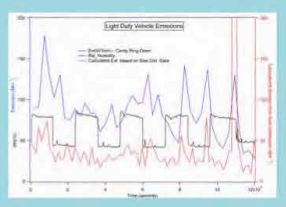
	PM2.5	TC	BC	OC	OC/BC
Heavy-Duty Diesel	0.67 ± 0.30	0.89 ± 0.09	0.47 ± 0.16	0.22 ± 0.10	0.5 ± 0.4
Light Duty Gasoline	0.05 ± 0.02	0.04 ± 0.01	0.02 ± 0.00	0.02 ± 0.01	0.8 ± 0.4
Ratio HD/LD	13	17	22	12	0.6
Ratio 2004/1997 HD	0.31	0.50	0.44	0.74	
Ratio 2004/1997 LD	0.66	0.75	0.80	0.69	

- Current heavy-duty particulate emission rates are about half of 1997 values
- On a fuel consumption basis, particle emission rates from heavy-duty vehicles are 10-20 times greater than from light-duty vehicles

Aethalometer Erroneously Indicates UV Absorption by Diesel Aerosols following filter tape advance



Controlled Relative Humidity Experiments: No Evidence of Particle Hygroscopic Growth



Closing Remarks

- Nearly exponential decreases in light-duty CO and NMOC emission rates since 1994
- On a fuel consumption basis, particle emission rates from heavy-duty vehicles are 10-20 times greater than from light-duty vehicles. On a per mile basis, the disparity is about four times larger.
- Good agreement between thermal-optical EGA and aethalometer measurements of BC
- Spectral light absorption by gasoline and diesel particles varies as $1/\lambda$ – typical of urban centers including Mexico City
- Fresh particulate emissions are not hygroscopic at relative humidities up to 80%

Indoor Exposures to Outdoor Contaminant Releases Summary of Experiments at Joint Urban 2003

LBNL Indoor Research Team:

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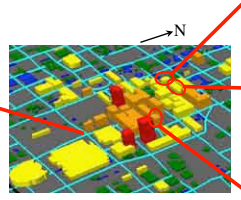
Introduction

In the event of an outdoor release of a chemical, biological or radiological material in an urban area most people will be in buildings, which is where most critical exposures occur. A series of outdoor tracer gas releases were conducted in Oklahoma City, OK, in July 2003 as part of a program to understand air flow and contaminant dispersion within complex urban areas. In conjunction with these tests, LBNL scientists performed experiments in three buildings located in the central business district.

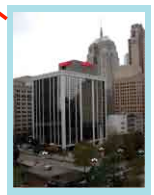
SF_6 tracer gas release location, looking North



- Isometric rendering of Oklahoma City central business district
- Buildings are colored by building height category

Building C: Small five story building: multiple HVAC systems with ground- and roof-level outside air intakes

Building B: Older retrofitted building, 3 to 9 stories. Multiple HVAC systems with outside air intakes at most floors in tower.



Building A: 1970s-style retrofit: 14 stories with outside air intakes at ground and roof levels. 15 HVAC systems, most vertically zoned

Indoor Study Objectives

Joint Urban 2003 provided an unprecedented opportunity to examine the coupling between outdoor releases and indoor exposures. The indoor experiments were designed to address three broad questions:

- *How do exposures to occupants in various parts of a building differ and how do they compare with exposures outdoors?*
- *How effective are proposed response strategies – such as shelter-in-place or manipulation of the building's heating and cooling system – for reducing indoor exposures?*
- *What are the transport pathways for airborne materials into buildings under various operating conditions?*

The experimental data can also be used to examine the coupling between interior and exterior transport models and to develop and calibrate multizone contaminant transport models.

Experimental Description

Detailed building investigations were conducted during April and May, 2003, in preparation for the July experiments. Measurements included:

- *HVAC flows and operations*
- *Building pressure manipulation to evaluate envelope leakage*
- *Building HVAC zones and interconnections*

During the July study, indoor experiments were conducted during four of the ten outdoor tracer release periods. Two tests were done under normal daytime building operations. Two other experiments examined shelter- or near-shelter conditions, i.e., periods when most of the HVAC systems were shut down.

Each experiment consisted of three 30 min outdoor SF6 releases, one every 2 hrs. In addition, three perfluorocarbon tracers (PFTs) were released at selected locations within each study building to examine indoor transport and dispersion. The indoor tracer releases, each 5 min long, were timed to coincide with the first and third outdoor tracer releases during each experiment.

Typical PFT Tracer Injection Locations

Rooftop air handler intake

Internal hallway

Acknowledgement

LBNL participation in Joint Urban 2003 was supported by the U.S. Department of Homeland Security, the Defense Threat Reduction Agency, the National Institute for Occupational Safety and Health and the U.S. Department of Energy under contract DE-AC03-76SF00098.

Instrumentation

Three multiplexed gas chromatographs (GCs) were deployed in two buildings for tracer gas sampling at selected interior and exterior locations. Measurement cycle time was ~ 4 min for SF6 and ~ 7 min for the PFTs. Forty-five multi-bag and 35 pairs of single-bag samplers were distributed indoors and outdoors (near buildings). Post-experiment tracer gas analysis was performed with GC-ECD systems to measure both SF6 and PFT concentrations. Assorted differential pressure, temperature, relative humidity, and flow instruments were deployed within and outside the buildings.

Multi-Bag Sampler

- *Programmable sampling intervals*
- *Sampling time is ~10 sec. per bag*
- *15 bags per air sampler system*

Single Bag Sampler

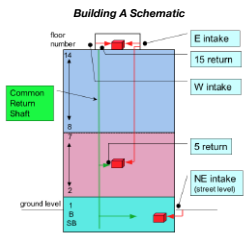
- *30 min integrated sampling interval*
- *Deployed in pairs to provide sequential sampling*
- *Bags changed manually to provide six hour coverage*

Results

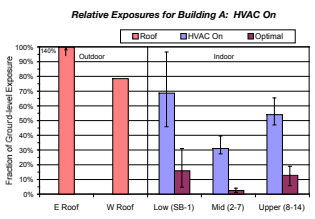
Tracer gas concentration profiles were integrated to estimate exposures at various locations within the buildings, under both normal (HVAC on) and shelter (HVAC off) conditions. Indoor exposures were calculated using indoor concentrations measured during the 2 hours after the first outdoor tracer release. The corresponding outdoor exposures were estimated from the concentration profiles measured at the building exterior.

In addition to comparing the indoor and outdoor exposure estimates under different building operation conditions, the effects of an 'optimal' shelter strategy were also estimated. This strategy assumes that building occupants evacuate the building when the outdoor tracer concentrations drop below the indoor tracer concentrations (typically 5 to 15 min after the end of the release).

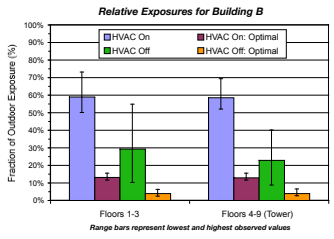
Building A Schematic



Relative Exposures for Building A: HVAC On

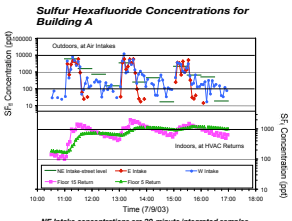


Relative Exposures for Building B



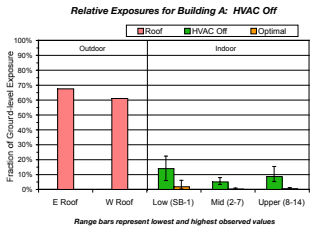
Range bars represent lowest and highest observed values

Sulfur Hexafluoride Concentrations for Building A



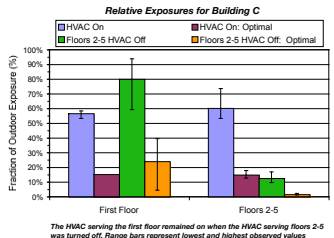
NE Intake concentrations are 30-minute integrated samples

Relative Exposures for Building A: HVAC Off



Range bars represent lowest and highest observed values

Relative Exposures for Building C



The HVAC serving the first floor remained on when the HVAC serving floors 2-5 was turned off. Range bars represent lowest and highest observed values

Summary

- *Occupant exposures can vary significantly both between buildings and within a single building.*
- *Sheltering in buildings can be an effective means of reducing exposure to outdoor contaminant plumes.*
- *Turning off the HVAC system can further reduce exposures (but most effective when prior to plume arrival).*
- *Optimized sheltering can have significant benefits, but evacuation to outdoors requires knowledge about outdoor contaminant conditions.*

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